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Robot Position Optimization for a Pick and Place Operation

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Abstract – In this paper, the robot position for pick and place operation has been optimized for three degree of freedom robot for minimum torque requirement. Robots mainly used for repetitive task and most common application is pick and place operation. For a given pick and place locations, robot manipulator may be fixed at different positions which directly affects the torque requirement at each joint and as a whole. Therefore, selection of optimum place for installation of robot for a given pick and place point is very important. Automated Dynamic Analysis of Mechanical Systems(ADAMS) was used for solving Inverse kinematics and dynamic simulation of robot. Forward kinematic equations are derived using Denavit-Hartenberg parameters. Iterative method is used for inverse kinematic solution in ADAMS software.

***Keywords*- forward and inverse kinematics, dynamics, ADAMS, trajectory planning, path tracking, DH representation.**

1. INTRODUCTION

The development in robotics area is increasing due to its wide applications such as automatic assembly, welding, painting and most important is operating in hazard conditions. Latest robotic research makes its installation more economic and has compact design thus saving power consumption and time.

Nowadays, most industries are using robots to increase production. Robots are mainly used for repetitive task which includes pick and place work, welding, painting etc. [1]. In these applications, robot follows fixed path for its entire life. In the industry, before robot employment, worker did that repetitive task. Every worker has some allotted space for its job in the industry. Human have a tendency to find comfort zone by its own. Due to this, worker will find a perfect working posture for which body feels less fatigue and works continuously. When industry replaces human worker with robot then it is very important to find an optimum place or posture for its installation. Optimum place for robot installation is that which consume less power and gives high life to robot. In present work, optimum place for robot installation will be recommended for a predefined pick and place position.

Robot design encompasses kinematic and dynamic analysis, selection of material and dimensions of the manipulator, determination of joint torques and motor selection etc. Articulated robots are most versatile regarding access to any point in its workspace. In the industry, articulated robots are mostly used. Different paths can be possible for different installation location of robot. These different paths also affect the power consumption of robot. Optimum place for robot installation can be selected in such a way that torque requirement at each joint is minimum, which can be calculated by dynamic simulation of robot along different possible paths [2]. However, formulation and analysis of robot dynamics is mathematically intensive task. Now a day, Simulation software are available using which comprehensive and accurate dynamic analysis of robot manipulator can be carried out. It is proposed to develop a system using Multibody dynamic software like MSC. ADAMS for simulating the kinematic and dynamic behavior of ABB IRB-140 articulated robot [3].

Fig 1.1 The IRB 140 CAD model

The ABB IRB 140 industrial robot has wide applications due to compact design. The main applications of IRB 140 industrial robot are Arc welding, spraying, machine tending, material handling and assembly etc. This robot has payload capacity of 5 Kg and with longest reachability of 810mm to fifth axis [4]. The CAD model of IRB 140 robot is shown in Fig.1.1.

2. OBJECTIVES

The primary objectives of the proposed work are given as:

1. To carry out kinematic and dynamic analysis of articulated industrial robot for a pick and place work.
2. To simulate the working of robot manipulator considering various path from start to target position.
3. Simulate the torque and velocity variation for different paths.
4. To determine the optimum location of robot for given pick and place operation.

3. KINEMATICS ANALYSIS OF ROBOT

Kinematic analysis of robot consists of forward kinematics and inverse kinematics. If all the joint angles are known then robot's end position can be determined by forward kinematic equations and to locate the robot's end at desire position then inverse kinematic equations help to determine each joint angle. These forward and inverse kinematic equations are derived using Denavit-Hartenberg representation for all possible configuration of robots, regardless of number of joints [5-6].

3.1. Inverse Kinematics

There are various methods by which inverse kinematic solution can be obtained. But most commonly used approaches are analytical approach, numerical approach and mixed approach [7]. Here, Inverse kinematic solution is obtained by optimization technique a numerical approach (Iterative method) using ADAMS software.

Optimization method is an iterative method in which it will try to minimize the distance between two points. This technique can be easily implemented in ADAMS software. The output of inverse kinematics are joint angles for particular position and all the angles are calculated from default position of robot which is shown in Fig.3.1. Inverse kinematic solution for desired position of robot's end was obtained by following steps:

a. Import CAD model of IRB 140 in ADAMS software in parasolid format.
b. The home position(Point-1) and target position(point-2) of robot's end is defined in (X,Y,Z) coordinates.
c. Create three design variables for three joints and define its maximum and minimum limit. For example, C rotation (joint-1) limit is 360° which is defined in ADAMS as maximum value 180° and minimum value -180° [9].
d. Create a distance measure between point-1 and point-2.
e. Apply optimization technique and define the objective to minimize the distance between two points while considering constraints on joints in terms of angle range which is already defined in step c.
f. Then start the iteration process which gives joint angles for three joints for position of point-2.
g. Save the Optimization report which provides all possible iterations made during the process.

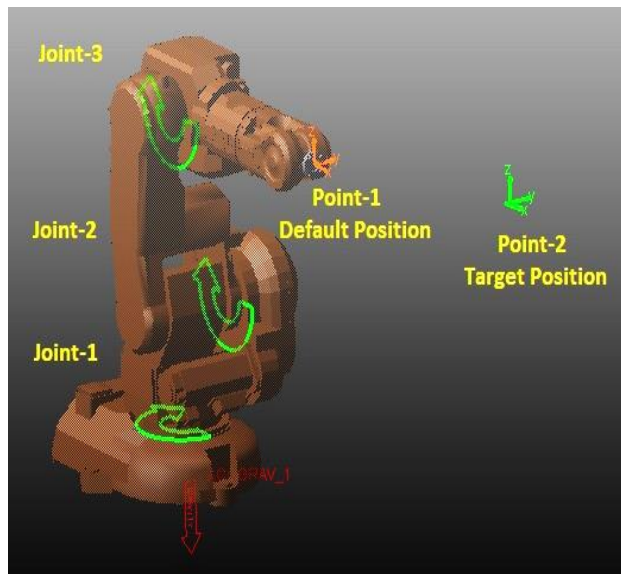

Figure 3.1 Optimization in ADAMS software

To verify the inverse kinematic solution obtained from ADAMS software, the values of the angles were substituted in the forward kinematic equations derived for the IRB 140 robot.

3.2. Forward Kinematics

Forward kinematic analysis of IRB 140 is obtained from Denavit-Hartenberg(DH) representation [5]. In DH representation, every joint which is under consideration assigned with reference frame. Then combine all the transformations from base to the last joint to get total transformation matrix [6]. Only first three joint of IRB 140 robot model are considered for the study. The reference frame for IRB 140 robot model for first three joint are shown in the Fig. 3.2

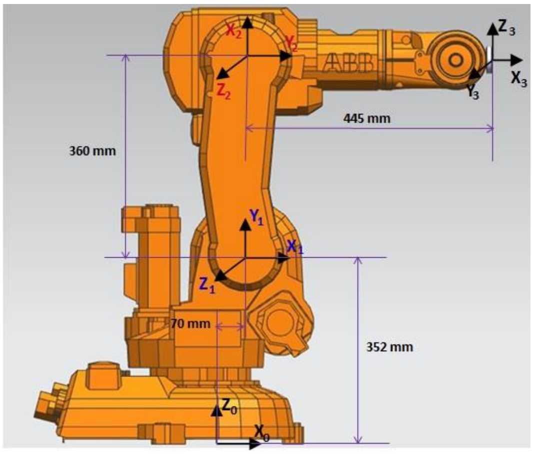

Figure 3.2 Reference frame for IRB 140 industrial robot

The DH parameters for the robot according to given reference frame are described in the Table 3.1.

Table 3.1 DH parameters for ABB IRB 140 Model

Links	θ	d	a	α
0-1	θ_1	352	70	90
1-2	θ_2 + 90	0	360	0
2-3	θ_3 - 90	0	445	-90

Now transformation matrix equations were solved for each joint according to above DH parameters. A1, A2 and A3 represents the homogeneous transformation matrix for the joint 1, joint 2 and joint 3 respectively.

$$A1=\begin{bmatrix} cos\theta_1 & 0 & sin\theta_1 & 70*cos\theta_1 \\ sin\theta_1 & 0 & -cos\theta_1 & 70*sin\theta_1 \\ 0 & 1 & 0 & 352 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$A2=\begin{bmatrix} -sin\theta_2 & -cos\theta_2 & 0 & -360*sin\theta_2 \\ cos\theta_2 & -sin\theta_2 & 0 & 360*cos\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$A3=\begin{bmatrix} sin\theta_3 & 0 & cos\theta_3 & 445*sin\theta_3 \\ -cos\theta_3 & 0 & sin\theta_3 & -445*cos\theta_3 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Now, multiply all the transformation matrix to obtain single homogeneous transformation matrix (T).

$$T= A1*A2*A3 \quad (4)$$

The final transformation matrix T will provide robot's end position in terms of (x, y, z) cartesian coordinates and orientation with respect to base frame for known values of θ_1, θ_2 and θ_3.

To find optimum position for robot installation fifteen positions were considered. All positions are within working range of IRB-140 robot. Each position is 100 mm apart from other which varies only in X-direction as shown in Fig. 3.3.

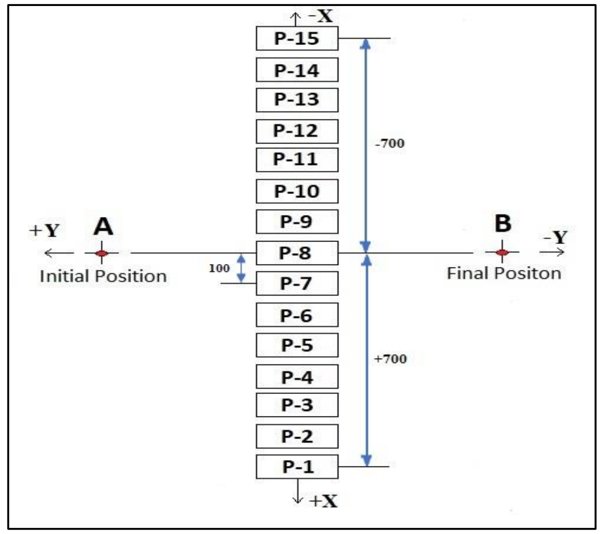

Fig. 3.3 Robot Installation positions

To verify the inverse kinematic solution from optimization technique of ADAMS software, out of fifteen positions first three positions P-1, P-2, and P-3 were considered. Position P-1, P-2 and P-3 of robot base, traces the path A1-B1, A2-B2, and A3-B3 respectively as shown in Fig. 3.4.

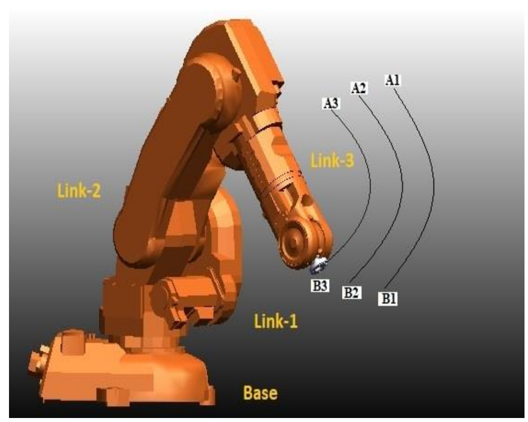

Figure 3.4 Path tracking

Inverse kinematic solution for end points of three paths A1-B1(path1), A2-B2(path2) and A3-B3(path3) were calculated. For the verification of the result, forward kinematic equations were solved for the joint angles obtained as solution from inverse kinematic. Robot's end position then compared with original position of end points for each path. Output of forward kinematics are compared with input of inverse kinematics and average percentage error was calculated which is shown in Table 3.2.

Table 3.2 Comparison of result obtained from ADAMS optimization and Forward kinematic

Sr No.	Path	End Points	Actual Position (mm)			Position obtained from Forward Kinematics			Percentage Error in Inverse Kinematics using ADAMS			Average %age Error (mm)
			X	Y	Z	X	Y	Z	X	Y	Z	
1	Path1	A1	700	400	600	699.764	400.227	599.440	0.034	0.057	0.093	0.061
		B1	700	-400	300	699.973	-399.958	299.852	0.004	0.011	0.049	0.021
2	Path2	A2	600	400	600	599.815	400.014	600.104	0.031	0.004	0.017	0.017
		B2	600	-400	300	599.981	-399.872	299.976	0.003	0.032	0.008	0.014
3	Path3	A3	500	400	600	500.134	399.987	600.000	0.027	0.003	0.000	0.010
		B3	500	-400	300	500.008	-400.000	300.080	0.002	0.000	0.027	0.009

The negligible percentage error obtained from all the fifteen paths validates the inverse kinematic solution obtained from ADAMS software.

4. DYNAMIC ANALYSIS

Dynamic analysis is related to load, mass, acceleration and inertia. The mostly used methods to solve dynamics of robot manipulator are Newton-Euler method and Lagrange-Euler method [6]. Parameters which considered in dynamic solution of robot in ADAMS software are material of manipulator, inertia matrix etc.

4.1. Mass properties and Inertia tensor

The material selected for manipulator have density-2110Kg/m3, young's modulus-60GPa and poisson's ratio-0.22. First three links are considered for the analysis which are shown in Figure 3.3. According to above properties of each link, mass of each link of robot is calculated in ADAMS [9] which is shown in Table 4.1.

Table 4.1 Mass of Robot manipulator

Sr. No.	Part of Robot	Mass in Kg
1	Base	26
2	Link-1	34
3	Link-2	16
4	Link-3	20

The general inertia matrix of a link is given in equation (5) and inertia matrix calculated by ADAMS software after defining the material for manipulator for each link are given in equation 6, 7 and 8 [9].

$$I = \begin{bmatrix} Ixx & Ixy & Ixz \\ Iyx & Iyy & Iyz \\ Izx & Izy & Izz \end{bmatrix} \quad (5)$$

$$I1 = \begin{bmatrix} 0.5554 & 0 & 0 \\ 0 & 0.4876 & 0 \\ 0 & 0 & 0.3757 \end{bmatrix} \quad (6)$$

$$I2 = \begin{bmatrix} 0.3286 & 0 & 0 \\ 0 & 0.2850 & 0 \\ 0 & 0 & 0.0871 \end{bmatrix} \quad (7)$$

$$I3 = \begin{bmatrix} 0.5017 & 0 & 0 \\ 0 & 0.4857 & 0 \\ 0 & 0 & 0.0745 \end{bmatrix} \quad (8)$$

5. TRAJECTORY PLANNING

Trajectory planning begins with proper selection of path and considering the time during which given path is covered. Different trajectories are obtained for given path by varying the time to cover that path. Proper selection of trajectory helps to minimized the power consumption, cycle time while considering manipulator constraints [8], [10]. For simulation of robot path in ADAMS software, parameters wiz. joint angle at initial position, joint angle at final position, simulation time and trajectory equation were provided. The robot joint angles for initial and final position were calculated using the inverse kinematics.

Considering the maximum TCP velocity and acceleration of IRB 140 model and distance between the initial and final point taken in pick and place operation, the simulation work carried out for 3 secs. The trajectory equation following third order polynomial was applied individually to each joint [10,11]. At beginning of motion of each joint at time t_i is at angle θ_i and which move to new angle θ_f at time t_f[3]. The general third order polynomial equation can be given as

$$\theta(t) = c_0 + c_1 t + c_2 t^2 + c_3 t^3 \quad (9)$$

Where, t is the simulation time, θ is the joint angle and, c_0, c_1, c_2 and c_3 are constants, which were determined from the following initial and final conditions.

$$\theta(t_i) = \theta_i \quad (10)$$

$$\dot{\theta}(t_i) = 0 \quad (11)$$

$$\theta(t_f) = \theta_f \quad (12)$$

$$\dot{\theta}(t_f) = 0 \quad (13)$$

Polynomial path used for the study which is shown in fig. 3.4 [8]. Each path has two end points whose value are known and correspond to these end points, robot's joint position in terms of angles (initial angle θ_i and final angle θ_f) were obtained from inverse kinematic solution from ADAMS software. For solution of polynomial equation, four constants have to be solved from above boundary conditions and its value in terms of initial and final angle are given below:

$$c_0 = \theta_i \quad (14)$$

$$c_1 = 0 \quad (15)$$

$$c_2 = \frac{3(\theta_f - \theta_i)}{{t_f}^2} \quad (16)$$

$$c_3 = \frac{-2(\theta_f - \theta_i)}{{t_f}^3} \quad (17)$$

Here initial time t_{i} is zero and t_f is the time to cover the path.

6. DYNAMIC SIMULATION

In dynamic simulation, torque and velocity variations are calculated for all joints of robot along all paths and these paths are correspond to fifteen installation positions of robot [6]. Each path simulated for 3 second for both loaded and unloaded condition at robot's end. The amount of load applied at robot's end will be 5kg. So, dynamic simulation is carried out in two parts i.e. Simulation-I and Simulation-II.

6.1. Simulation-I

In this simulation, each path is covered in 3 second ($t_f = 3s$) without payload at robot's end. All simulations are carried out in ADAMS software [12-13]. The torque variation at each joint without payload for all fifteen positions are shown in Fig. 6.1 shows torque variation for all installation position of robot without payload.

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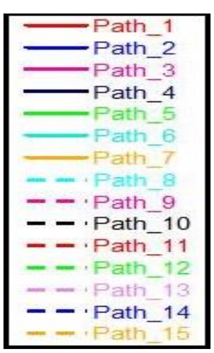
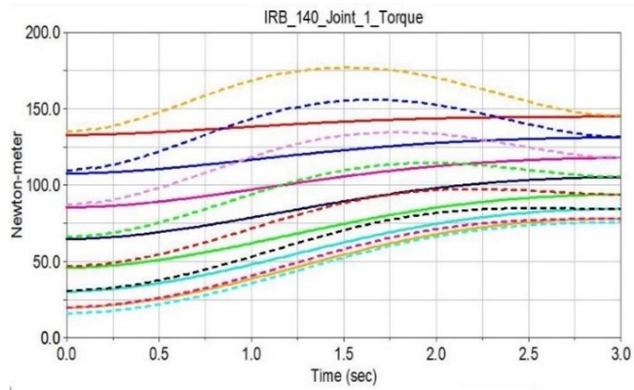
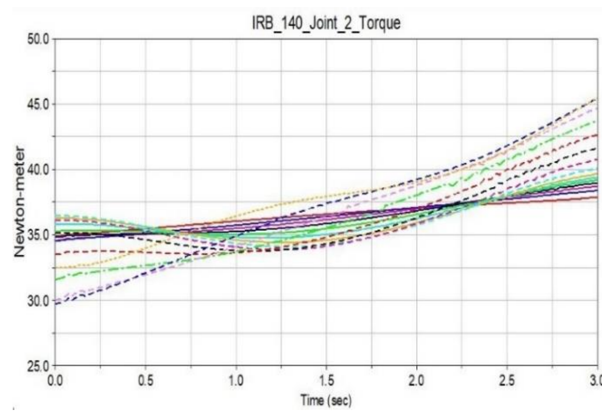


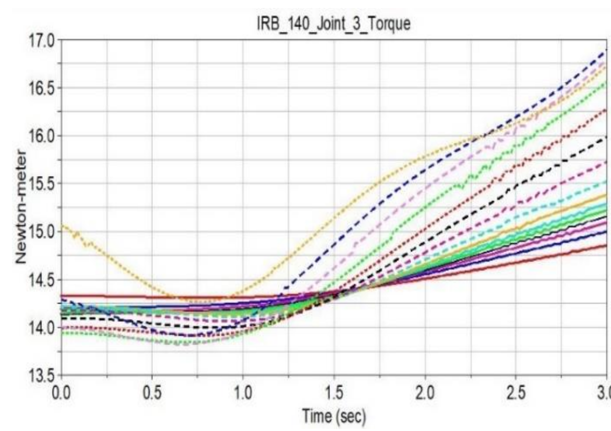
Fig. 6.2 shows the total torque for all joints of robot for all installation position of robot and Angular Velocity variation at each joint are shown in Fig. 6.3.



(a)



(b)



(c)

Fig. 6.1 Torque variation at each joint during path covered in 3 second without payload (a) Joint-1 (b) Joint-2 (c) Joint-3

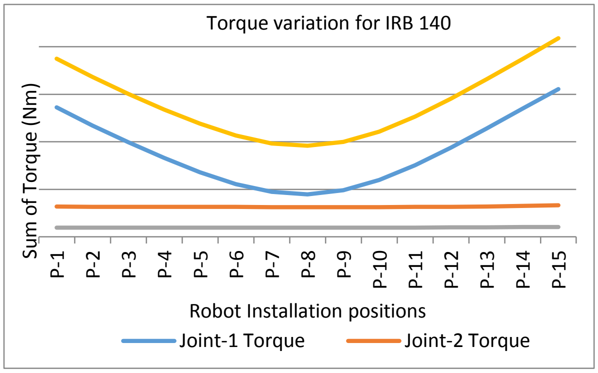
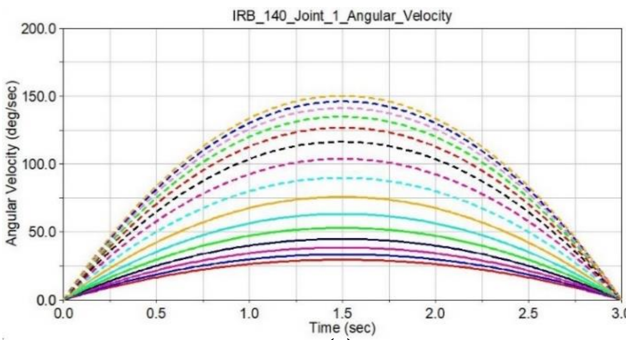
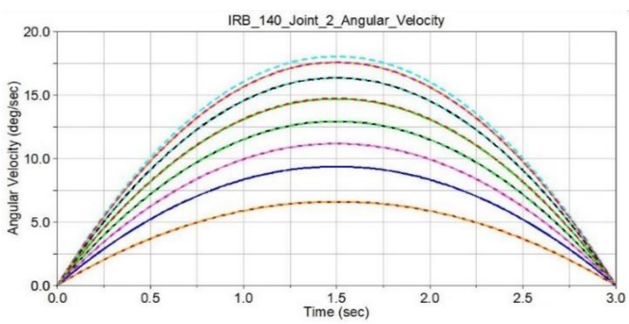


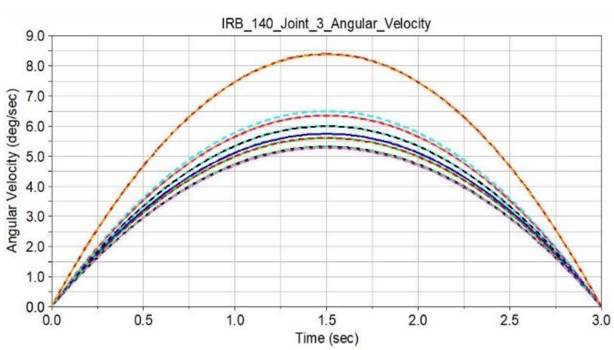
Fig. 6.2 Torque variation for different installation position of IRB 140 robot



(a)



(b)

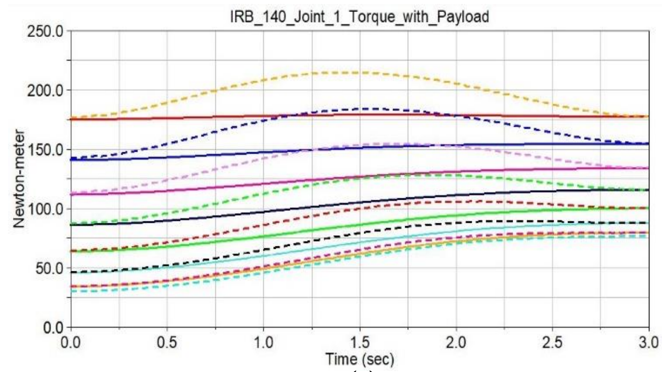


(c)

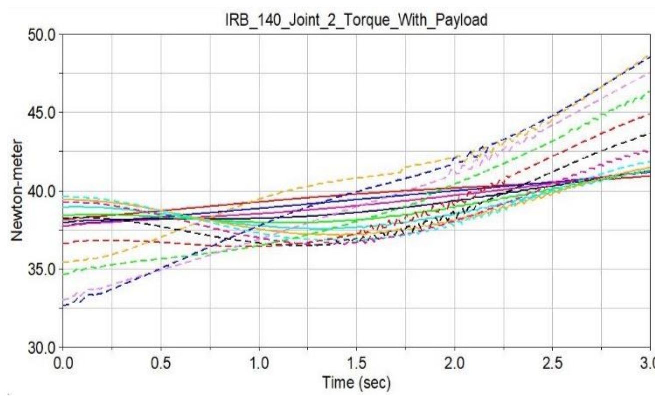
Fig. 6.3 Angular Velocity variation at each joint during path covered in 3 seconds (a) Joint-1 (b) Joint-2 (c) Joint-3

6.2. Simulation -II

In this simulation, each path is covered in 3 second ($t_f = 3s$) with payload of 5Kg at robot's end. The graph for torque variation at each joint with payload are shown in Fig. 6.4.



(a)



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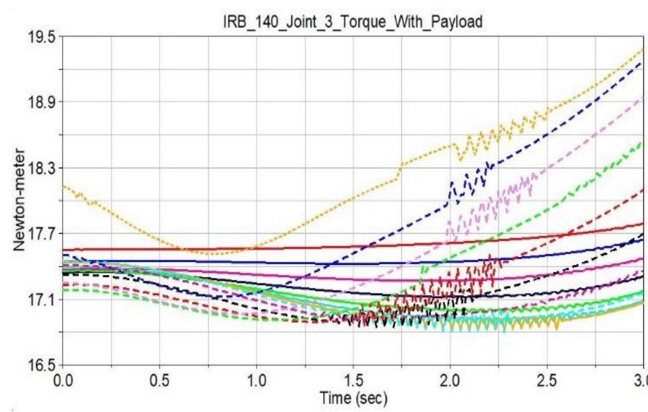

(c)

Fig. 6.4 Torque variation at each joint during path covered in 3 seconds with payload (a) Joint-1 (b) Joint-2 (c) Joint-3

The graph for velocity and acceleration variation at robot's end are shown in Fig. 6.5 and 6.6. Variation of path covered by robot's end along X-axis and Y-axis is shown in Fig. 6.7.

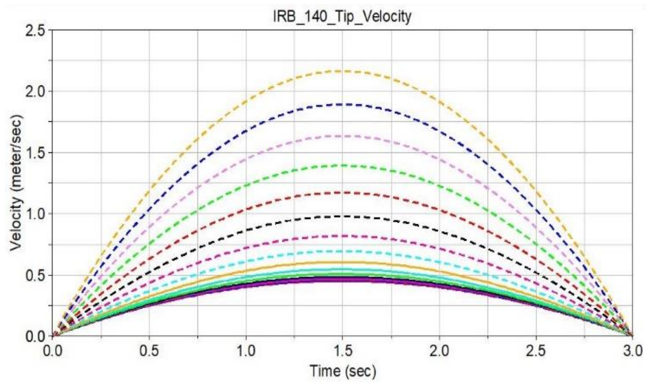

Fig. 6.5 Velocity variation at Robot's end (Tip Velocity)

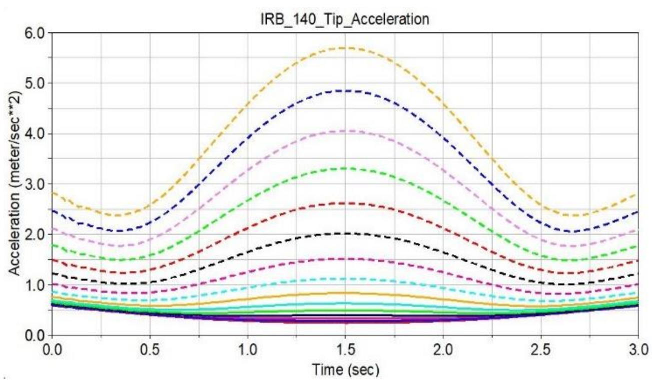

Fig. 6.6 Acceleration variation at Robot's end (Tip Acceleration)

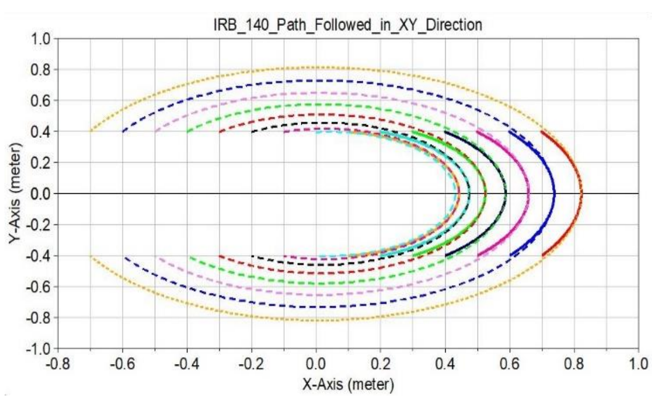

Fig. 6.7 Path traced by Robot's end along X and Y direction

7. CONCLUSIONS

The forward kinematic equations were derived from Denavit-Hartenberg parameters and a procedure was developed to solve the inverse kinematic problem for particular position using optimization technique (Iterative method) in ADAMS/View software. This method requires very less manual mathematical derivation of equations. The percentage error obtained in validation of inverse kinematic solution by ADAMS software is with in positional accuracy of ABB IRB-140 robot model. The third order polynomial trajectory planning was used for each joint for all paths which corresponds to different position of robot base. Two parameters were varied as input i.e. position of robot installation and payload. Paths for all location of robot base were followed by robot's end with payload and without payload. The simulation along these paths were run on ADAMS/View to calculate variation of torque, velocity at each joint and variation of velocity, acceleration at robot's end.

It was observed that torque requirement at each joint increase as the robot installed farther from pick and place locations. The result show that position P-1 and P-15 requires more torque as compare to other positions of robot for both loading and unloading condition. So, power consumption is more for the position P-1 and P-15 as compare to other positions.

The minimum torque was obtained at joint-1 for position P-8 of robot which is closest to pick and place points. But Joint-2 and Joint-3 torque variation shows that too close installation of robot also increases the power consumption. Out of all fifteen-installation positions of robot position P-8 is recommended which requires minimum torque.

In the present work, simulation work carried out for only one-time period. By simulating the pick and place operation for different time period, the torque requirement for different robot positions as well as different tip velocities may be computed. The approach presented in this paper may be used to select the optimum position of fixing a robot for a pick and place operation while considering the time and robot physical constraints.

REFERENCES

[1] Cheraghpour, F., Vaezi, M., Jazeh, H.S. and Moosavian, S.A.A., 2011, April. Dynamic modeling and kinematic simulation of Stäubli© TX40 robot using MATLAB/ADAMS co-simulation. In Mechatronics (ICM), 2011 IEEE International Conference on (pp. 386-391). IEEE.

[2] Inigo, R.M. and Morton, J.S., 1991. Simulation of the dynamics of an industrial robot. IEEE Transactions on Education, 34(1), pp.89-99.

[3] Gasparetto, A., Boscariol, P., Lanzutti, A. and Vidoni, R., 2012. Trajectory planning in robotics. *Mathematics in Computer Science*, *6*(3), pp.269-279.

[4] ABB Robotics, IRB 140, http://new.abb.com/products/robotics/industrial-robots/irb-140

[5] Atique, M.M.U. and Ahad, M.A.R., 2014, May. Inverse Kinematics solution for a 3DOF robotic structure using Denavit-Hartenberg Convention. In *Informatics, Electronics & Vision (ICIEV), 2014 International Conference on* (pp. 1-5). IEEE.

[6] Niku, S.B., *Introduction to Robotics: Analysis, Control, Applications*. Second edition, John wiley & Sons Inc., pp. 178-200.

[7] RATIU, M., 2016. Short literature review on the kinematics and dynamics of the industrial robots. *Annals of the University of Oradea, Fascicle of Management and Technological Engineering*, (2), pp.49-52.

[8] Suárez, M.B. and Heredia, R.R., 2013, October. Kinematics, dynamics and evaluation of energy consumption for ABB IRB-140 serial robots in the tracking of a path. In *The 2nd International Congress of Engineering Mechatronics and Automation* (pp. 23-25).

[9] Hroncová, D., Binda, M., Šarga, P. and Kičák, F., 2012. Kinematical analysis of crank slider mechanism using MSC Adams/View. *Procedia Engineering*, *48*, pp.213-222.

[10] Biagiotti, L. and Melchiorri, C., 2008. *Trajectory planning for automatic machines and robots*. Springer Science & Business Media.

[11] Lin, C., Chang, P. and Luh, J., 1983. Formulation and optimization of cubic polynomial joint trajectories for industrial robots. *IEEE Transactions on automatic control*, *28*(12), pp.1066-1074.

[12] Talli, A.L. and Kotturshettar, B.B., 2015. Forward Kinematic Analysis, Simulation & Workspace Tracing of Anthropomorphic Robot Manipulator By Using MSC. ADAMS. *International Journal of Innovative Research in Science, Engineering and Technology*, *4*.

[13] Li, Y.W., Wang, J.S., Wang, L.P. and Liu, X.J., 2003, September. Inverse dynamics and simulation of a 3-DOF spatial parallel manipulator. In Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on (Vol. 3, pp. 4092-4097). IEEE.